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QUARTERLY PROGRESS REPORT No. 7

July 1962 through September 1962

Effect of Nuclear Radiation on materials at Cryogenic Temperatures

PREPARED UNDER

National Aeronautics/Space Administration Contract NASw-114

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LOCKHEED NUCLEAR PRODUCTS

Lockheed-Georgia Company A Division of Lockheed Aircraft Corporation

Contract: NASw-114	Code: U

FOREWORD

This quarterly report is submitted to the Office of Space Launch Vehicles of the National Aeronautics and Space Administration in accordance with the requirements of NASA Contract NASw-114.

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1 INTRODUCTION AND SUMMARY

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Progress made during the period of July 1, 1962 through September 30, 1962 on Contract NASw-114 is described in this report. This report provides a summary of temperature measuring techniques in addition to the activities relevant to installation of test equipment at the Plum Brook Reactor Facility.

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2 SUMMARY OF TEMPERATURE MEASUREMENT TECHNIQUES

For the proper execution of this program, a satisfactory method for the measurement and control of the temperatures of the specimens during irradiation and testing was developed. These temperatures range from $30^{\circ}R$ to $540^{\circ}R$. The effects of nuclear radiation on the response of temperature sensors and the heat generated within the sensors by the radiation make this difficult problem even more complicated.

Attachment of temperature sensors, such as thermocouples to each test specimen is impractical from a procedural standpoint, and, from the technical standpoint, would invalidate the mechanical properties data sought. Early in the planning of this program, these factors were recognized. An agreement was reached with NASA to control the temperature of the refrigerant gas surrounding the specimen and thereby control the specimen temperature. To do this, the relationship between the gas temperature and the specimen temperature must be accurately known and the gas temperature must be measured and controlled with the required accuracy.

This problem consists of three types of measurements. One is to accurately measure the specimen temperature, the second is to measure and control the gas temperature, and the third is to establish the gas temperature at the control point required to produce the desired temperature in the specimen.

As a result of conferences of NASA and Lockheed technical personnel, Lockheed was requested to initiate and execute an intensified thermocouple measurement program to develop techniques for the measurements at Plum Brook.

These experimental studies included thermocouple wire selection, calibration of thermocouples, and measurement of temperature gradients in test specimens without irradiation.

2.1 THERMOCOUPLE WIRE SELECTION

Preliminary evaluations were made to verify the relative quality of available thermocouple materials. These indicated that, on the basis of homogeneity and sensitivity at cryogenic temperatures, copper-constantan and gold-cobalt possess the most desirable characteristics. Copper-constantan was selected for the first series of temperature measurements. The wire used was No. 30 B & S gage copper and constantan from Leeds and Northrup stock No. 6-0-55-1, spool no. 17150-9. Each wire was insulated with enamel covered with fiberglas insulation, then the two wires were encased in fiberglas insulation. The wire was tested for homogeneity. Figure 1 is a block diagram of the test apparatus. The electrical section of the test equipment consists of a Kin Tel electronic galvanometer and a Sanborn 150 series recorder with a type 150-1000 preamplifier. This equipment was calibrated to provide a system sensitivity of 2 microvolts per centimeter on the recorder chart.

The thermoelectric section of the system consisted of an 18-foot length of the copper-constantan thermocouple wire in which the loop under test was either the copper wire or the constantan wire. The wire was supported above a track on which a small liquid air bath was transported. An arrangement, shown in Figure 2, by which a 6-inch section of the wire was submerged in the liquid air was used. At the beginning of the test, the instrumentation was balanced for the 6-inch section of submerged wire. During the test, the bath was pulled along the wire (in 8-foot sections) at a rate of approximately 3 inches per minute which moved the two thermal gradients along the length of the wire. After the initial submersion, the Thompson emf developed at each of the two temperature gradients, while these gradients were slowly moved along the length of the wire, would be equal, provided no Peltier emf caused by lack of homogeneity in the wire were present. The instrumentation recorded any difference in emf that developed as the thermal gradients were moved from the length of the wire. Wire that did not develop more than 3 microvolts change in voltage, due to movement of the temperature gradients, in a 1.5 foot length from the thermocouple junction was selected for the

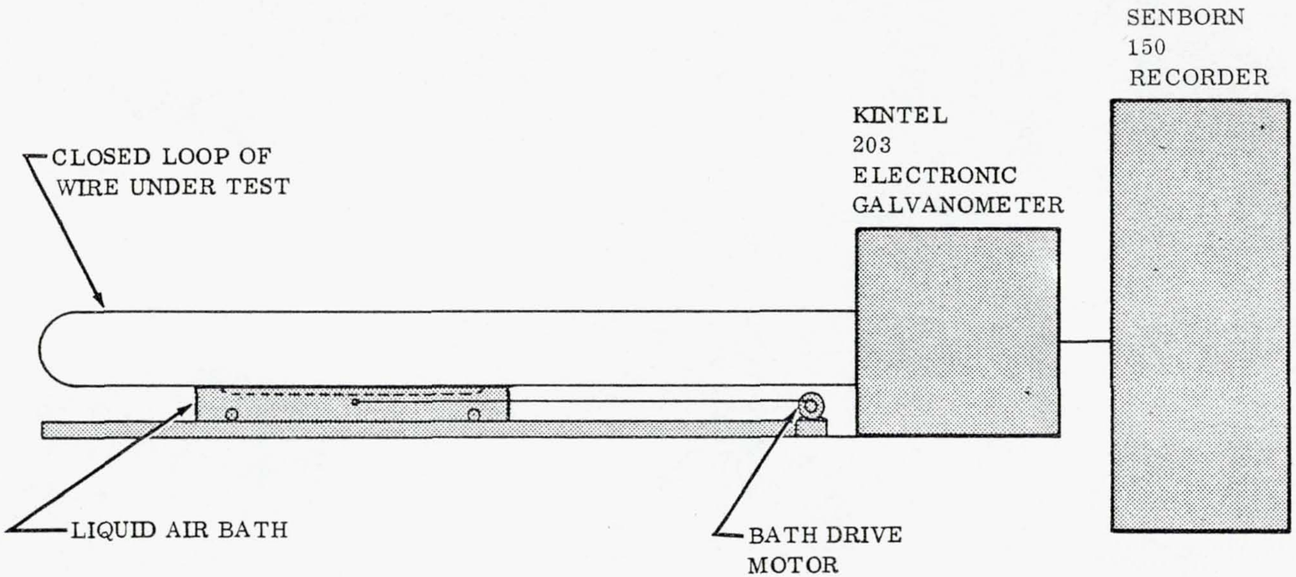

FIGURE 1 THERMOCOUPLE WIRE SELECTION APPARATUS

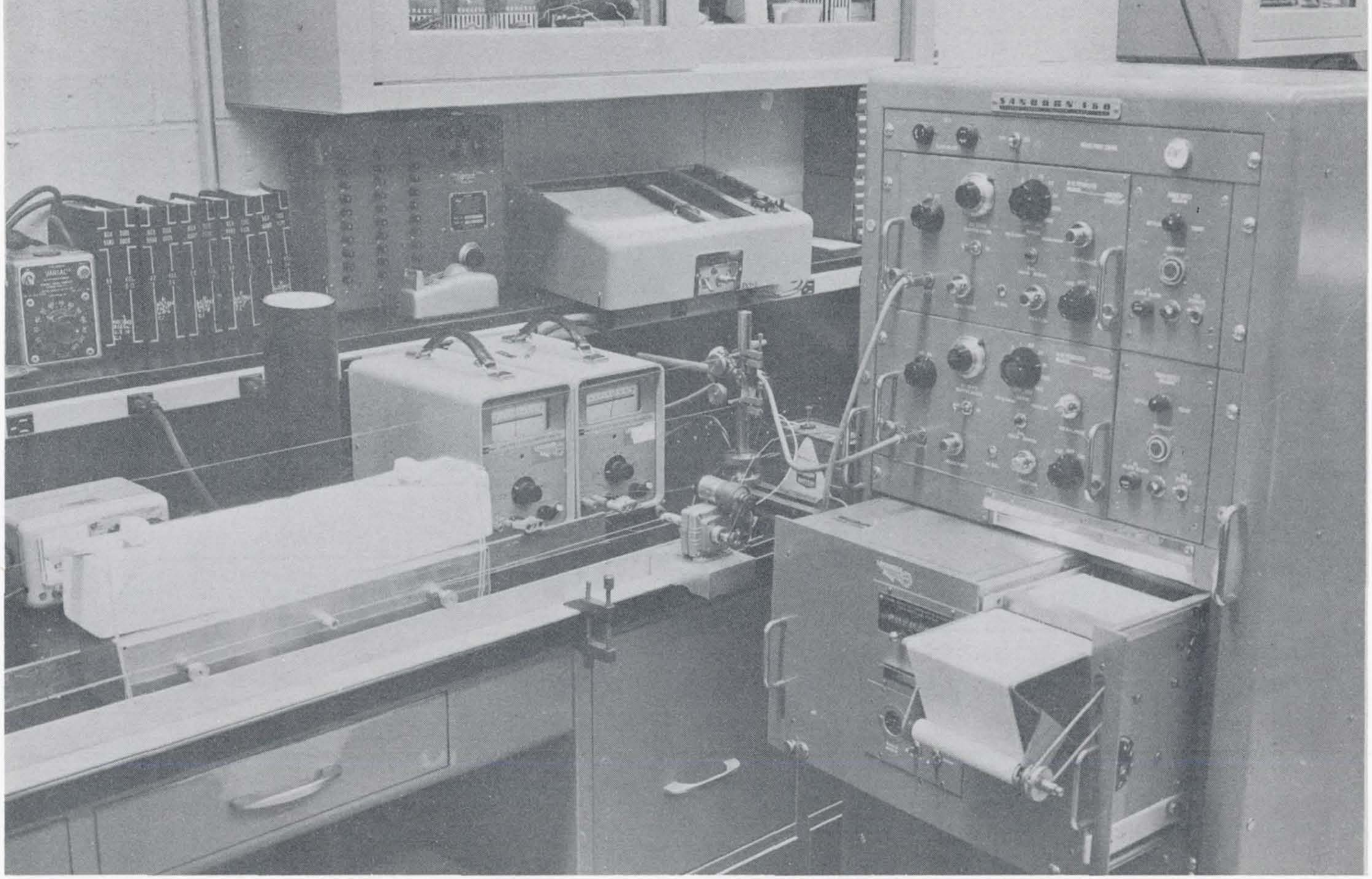

FIGURE 2 THERMOCOUPLE WIRE TEST APPARATUS

thermocouples. This 1.5 foot length is more than that portion of the thermocouple which will be exposed to high thermal gradients in the test loop. Typical test data for rejected wire is shown in Figure 3 and for accepted wire in Figure 4.

2.2 THERMOCOUPLE CALIBRATION

The thermocouples were calibrated by measuring the emf developed at various temperatures from room temperature to 22^{o}R. These temperatures were obtained in the test loop and were measured with a 4 terminal platinum resistance thermometer that had been calibrated for this temperature range by the National Bureau of Standards. A Mueller bridge and mercury commutator switch were used with the resistance thermometer. The thermocouple reference temperature was obtained with an ice bath and the thermal emf was measured with a K-3 potentiometer and a Leeds and Northrup Speedomax G indicator with 1 microvolt system sensitivity.

In the test loop head assembly, the platinum resistance thermometer and the thermocouple measuring junctions were mounted in an aluminum cavity to provide better temperature equalization than would have been obtained by mounting them in the gas stream without this shield. An unshielded thermocouple with its recorder was provided to indicate the gas temperature thus permitting the test loop operator to maintain stable temperatures during the data collecting periods. A block diagram of the equipment is shown in Figure 5. In addition to the calibration in the test loop, the thermocouples and the resistance thermometer were immersed in a liquid air bath to provide a check point with a minimum ΔT between the resistance thermometer standard and the thermocouples being calibrated. The calibration results are presented in Figure 6. The sensitivity of the platinum resistance thermometer system and the stability of the cooling system permitted calibration of the thermocouples to an accuracy better than $\pm 0.5^{o}$R.

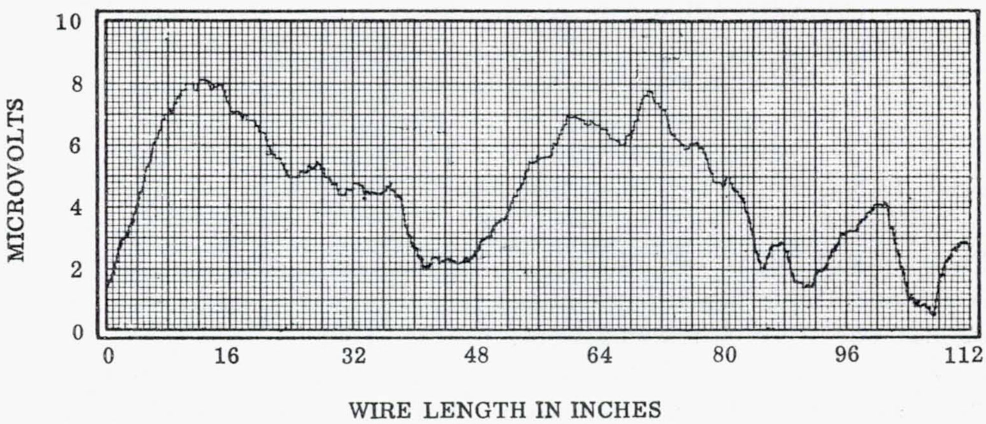

FIGURE 3 TYPICAL WIRE TEST DATA - REJECTED WIRE

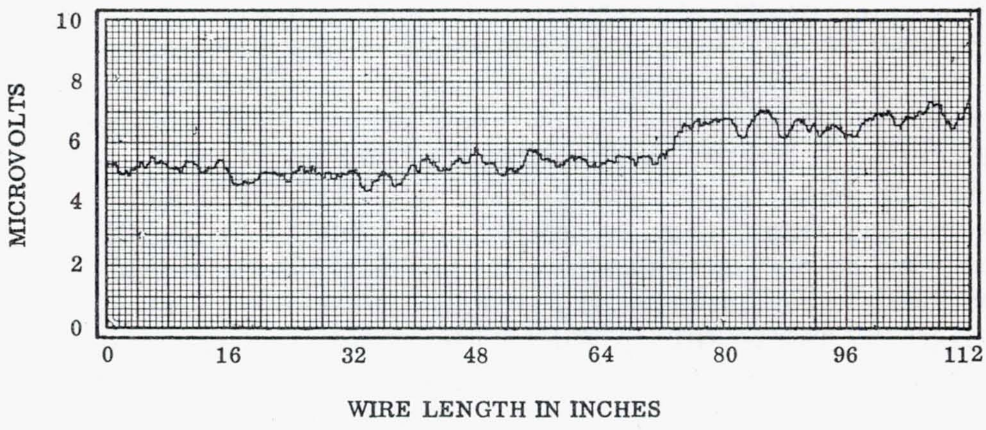

FIGURE 4 TYPICAL WIRE TEST DATA - ACCEPTED WIRE

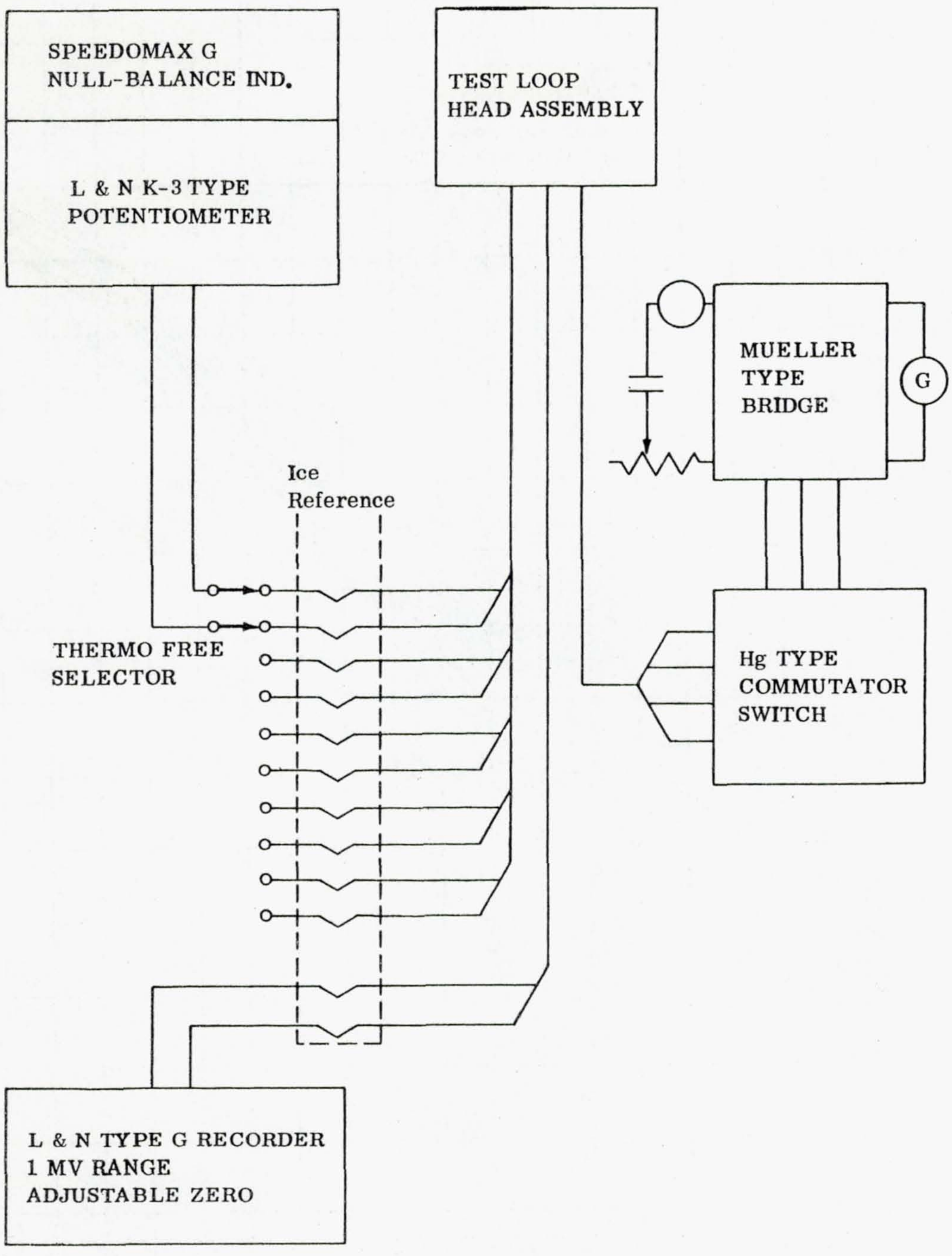

FIGURE 5 THERMOCOUPLE CALIBRATION EQUIPMENT

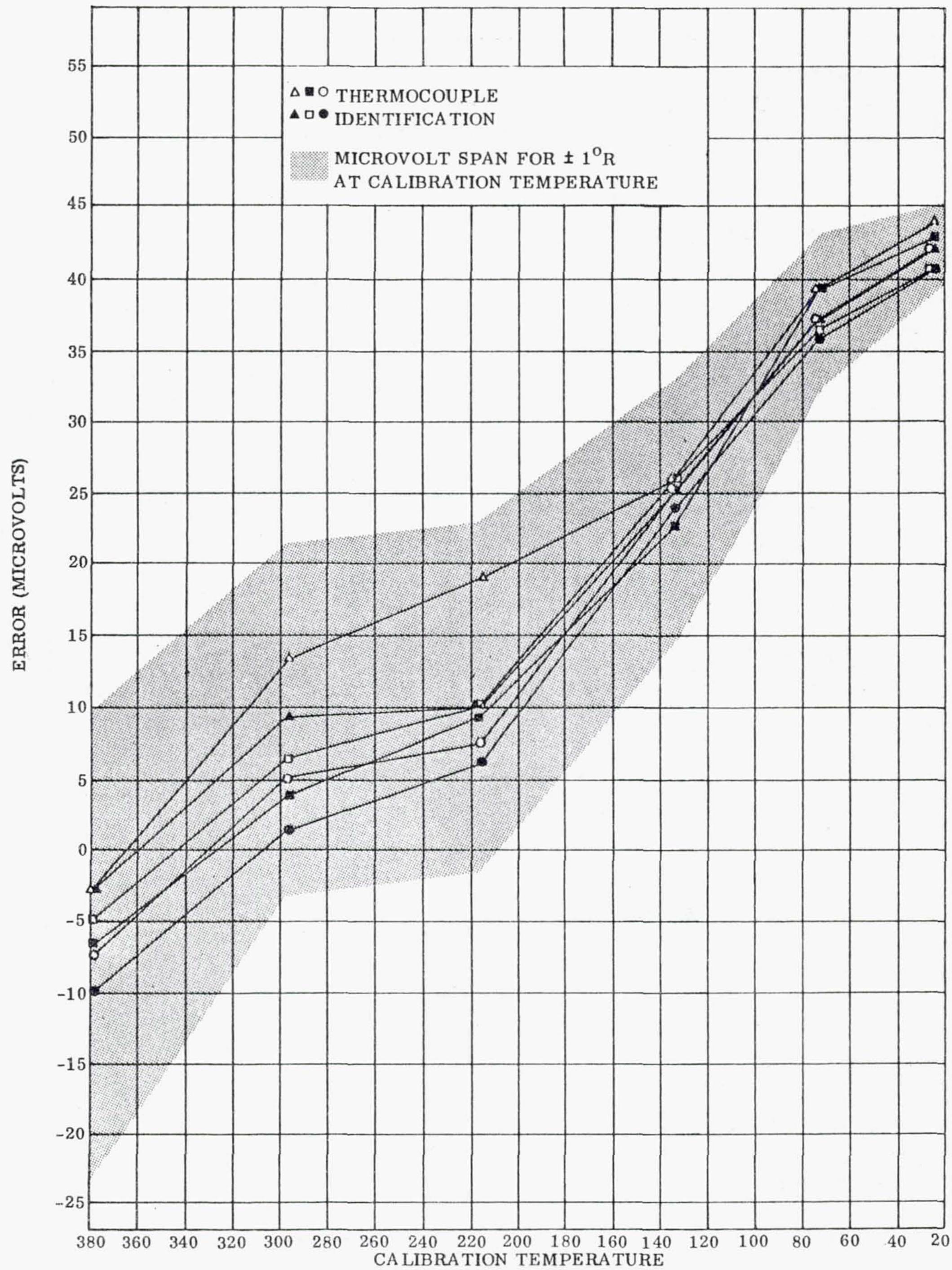

FIGURE 6 THERMOCOUPLE CALIBRATION RESULTS

2.3 SPECIMEN TEMPERATURE DISTRIBUTION

A sample of 4130 steel was prepared with five thermocouples resistance welded to the sample, one thermocouple resistance welded to the sample holder, and two thermocouples mounted in the helium return line. The location of the thermocouple junctions and the wire positions are shown in Figure 7.

A diagram of the temperature measuring system that was used for these measurements is shown in Figure 8. The system accuracy is $\pm 1.6^{o}$R. The system sensitivity allowed the temperature gradients in the sample to be measured within $\pm 1^{o}$R in the span near 140^{o}R and near 30^{o}R. The resultant temperature measurements and temperature gradients are presented in Figure 9.

The measured temperature gradients between the centerline of the test specimen and the two gage points indicate that the No. 30 B and S gage thermocouple wire may be introducing an appreciable error in the apparent sample measurements. To resolve this question, the test was re-run with the thermocouple leads being positioned to the other end of the sample, changing the heat path. The second arrangement is shown in Figure 10 and the resultant temperature gradients for three temperatures are shown in Figures 11, 12, and 13. In this test a 304 stainless steel specimen was used.

The above test data show that truer temperature indications of an uninstrumented sample will be obtained by use of thermocouples with less heat transfer capabilities.

The data presented in Figure 13 show that the temperature distribution in the test sample is not isothermal; however, this is due to the fact that with the GNL system (not the case for the Plum Brook system) to decrease the temperature, the rpm of the expansion engines must be decreased, thus decreasing the mass flow which decreases the heat transfer coefficient. Therefore, it is obvious that this method of temperature control must not be used, but that either a variable heater needs to be put in the inlet line or

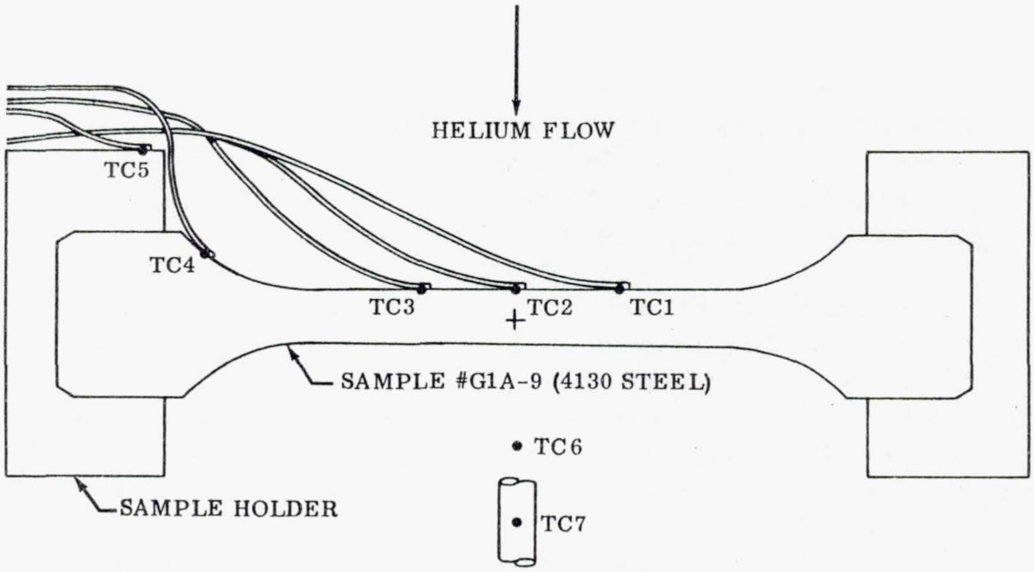

FIGURE 7 THERMOCOUPLE JUNCTION AND WIRE LOCATION SPECIMEN 4130 STEEL

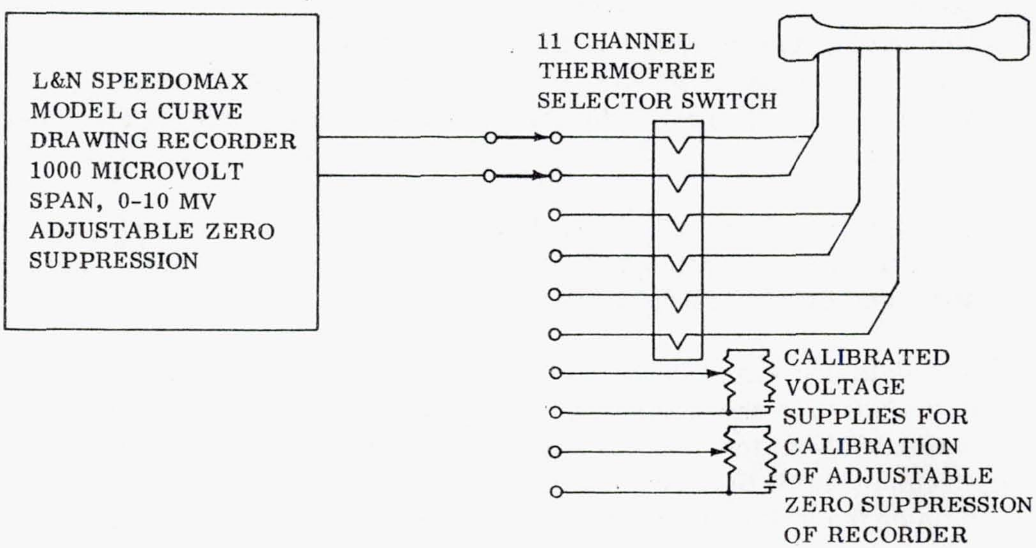

FIGURE 8 TEMPERATURE GRADIENT MEASURING SYSTEM

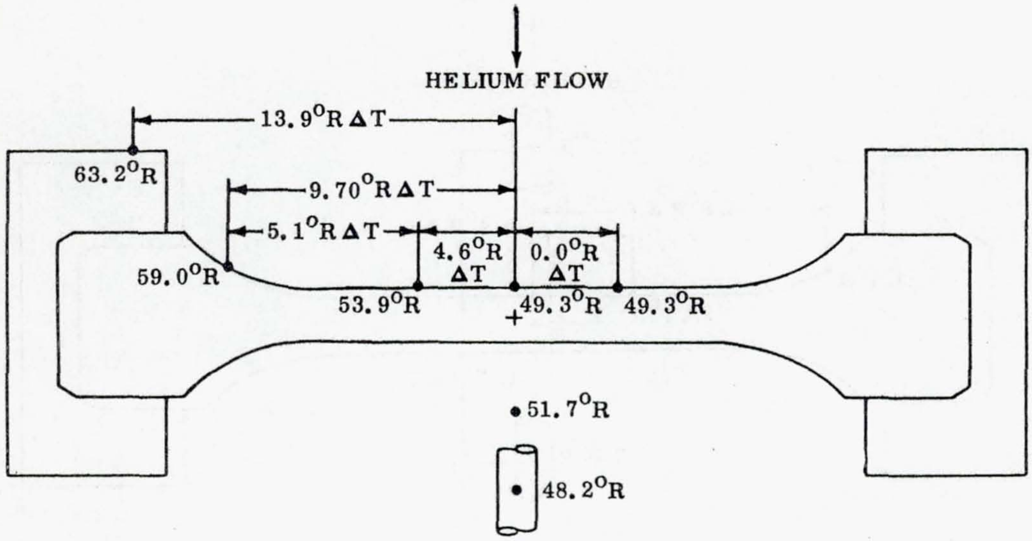

FIGURE 9 TEMPERATURES AND TEMPERATURE GRADIENTS
SPECIMEN 4130 STEEL

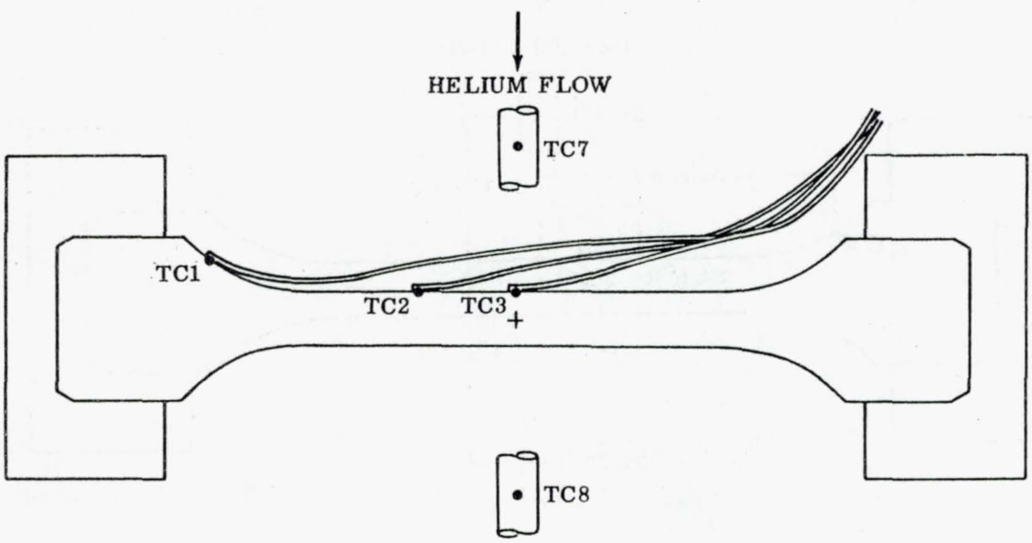

FIGURE 10 THERMOCOUPLE JUNCTION AND WIRE LOCATIONS
SPECIMEN 304 STAINLESS STEEL

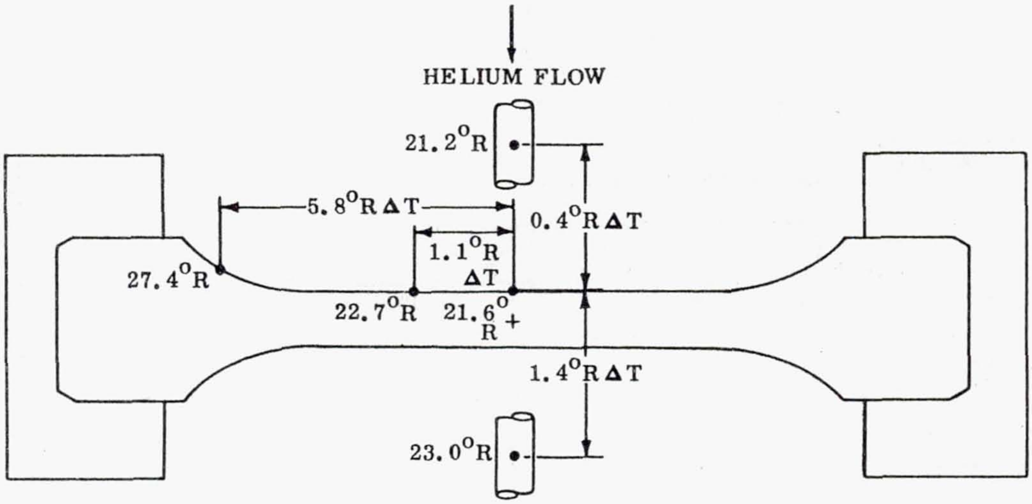

FIGURE 11 TEMPERATURES AND TEMPERATURE GRADIENTS - 304 STAINLESS STEEL AT 22°R

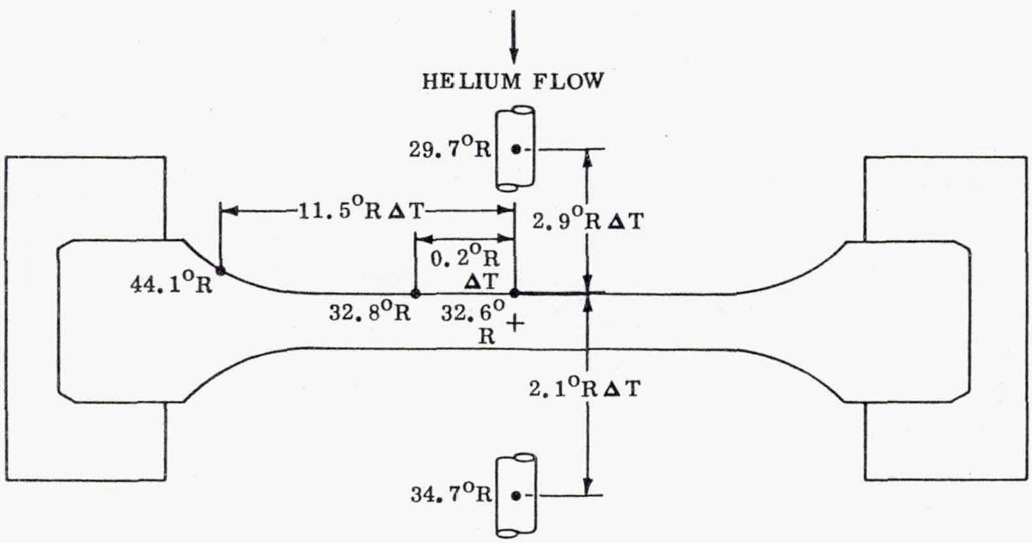

FIGURE 12 TEMPERATURES AND TEMPERATURE GRADIENTS - 304 STAINLESS STEEL AT 32°R

warm helium bled into the inlet line. This problem will be corrected by the latter means. The system at Plum Brook provides temperature regulation by the former means at constant expansion engine rpm and constant mass flow.

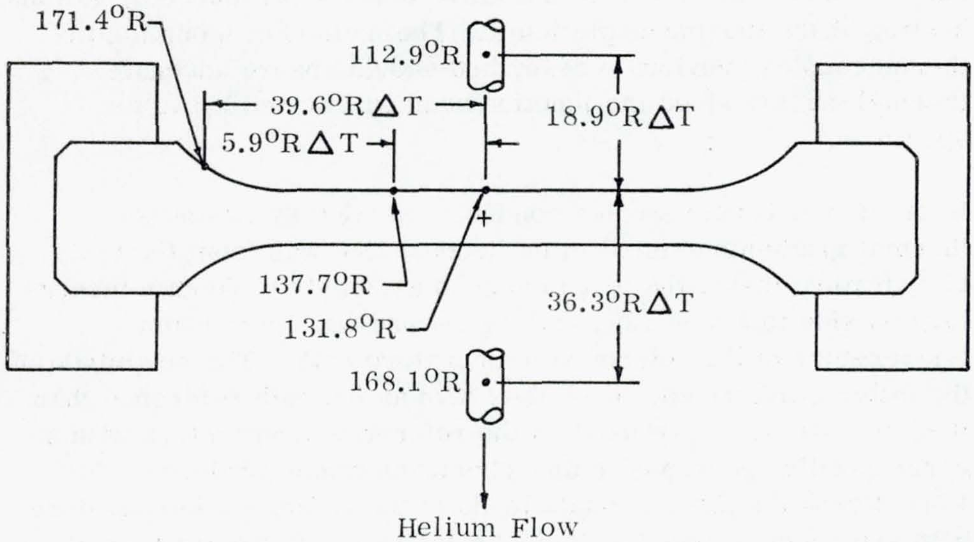

FIGURE 13 TEMPERATURES AND TEMPERATURE GRADIENTS - 304 STAINLESS STEEL AT 132°R

The results presented above were discussed with NASA technical personnel and the following refinements were incorporated into the method of measuring specimen temperatures. Smaller (No. 40 or No. 36 B & S gage) wire was used for the thermocouples. The thermocouple junctions were welded to the bottom of a small axial groove in the specimen surface with the leads also mounted in the groove in thermal contact with the specimen for the maximum available distance. After the thermocouples were mounted, the groove was filled with a suitable potting compound to prevent perturbations in the gas flow pattern around the specimen when mounted in the test loop. Only three thermocouples were used - one mounted at each end of the gage length and one in the center of the gage.

Measurements at ORNL of copper-constantan thermocouple in a liquid helium bath have shown that a neutron dose of 10^{18} pile neutrons had a negligible effect on the thermoelectric power; therefore, no significant error in temperature measurement is expected from neutron effects. Special precautions will be required, however, to ensure good thermal contact of the thermocouple with the specimen to minimize errors introduced by gamma heating of the thermocouple itself. The method of mounting the thermocouples previously described should ensure adequate thermal contact since the junction bead will be welded to the specimen.

In the thermocouple studies conducted at AFP 67 two major thermal gradients existed in the leads. One was from the test temperature inside the test loop head assembly to room temperature outside this assembly and the second was from room temperature to the reference temperature bath. The magnitude of the latter gradient was much less with an ice bath reference than if liquid nitrogen were used as the reference temperature with a corresponding decrease in any Thompson effect produced. At Plum Brook the thermocouple leads to the reference temperature bath are about 30 feet long (about a factor of 10 greater than at AFP 67). In addition, there are three major thermal gradients. One is from the test temperature to approximately $585^{o}K$ where the leads emerge from the head to the aft assemblies in the test loop. The second is from $585^{o}K$ to about $530^{o}K$ where the leads leave the aft end of the test loop and enter the pool water and the third is between the pool and the reference temperature bath. Those sections of the thermocouple leads which traverse these thermal gradients must be homogeneous to prevent the Thompson emf generated from nullifying the validity of the temperature data since the output of a copper-constantan couple in the low temperature range (18-45^{o}R) is of the order of 0.7 to 4.5 microvolts per ^{o}R.

2.4 REFRIGERANT GAS TEMPERATURE MEASUREMENT AND CONTROL

As initially planned; the refrigeration system was to be controlled by electrical signals generated in a platinum resistance thermometer mounted in the helium inlet duct near the point where it enters the head assembly of the test loop. Data only recently available from ORNL indicate that the radiation effects on the resistance of platinum are of a magnitude that precludes the use of the proposed control method. ORNL reports that the resistivity of platinum increases by 6×10^{-8} ohm/cm for a neutron dose of 10^{18} fast neutrons (of 1/E energy distribution - 10^{17} nvt above 1 mev). Also, the resistivity changes by 4×10^{-8} ohm/cm when the temperature is increased from 28.8°R to 30.6R. Since experiments have shown that this enhanced resistivity does not obey Mathieson's law, and the radiation induced resistivity was measured at 7.5°R, the actual effect may be greater than the data indicate. Warming the platinum to room temperature will remove about 70 to 80 percent of the radiation induced resistivity. Thus, the thermometer would require calibration after each irradiation and even then would have an uncertainty of about 3°R.

Lead resistance thermometers are much better than platinum resistance thermometers with respect to radiation effects, but, because of their fragile nature, lead thermometers would not be satisfactory for this application. Radiation induced resistivity in lead is also removed by warming. At 135°R approximately 35 percent of the resistivity induced by irradiation at 7.5°R is removed.

Carbon resistors have been investigated. At temperatures below 180°R the radiation induced resistivity was a small fraction of the total resistance when those with high specific resistance were tested. The low thermal conductivity of carbon would introduce an error due to the lack of removal of the gamma heat generated in the resistor. It has been predicted that in this application the gamma heating would cause the thermometer to indicate a temperature much higher than the actual temperature - if the sensor is located in the inlet gas stream, the indicated temperature would probably be higher than the actual temperature of the exhaust gas.

Although thermocouples under carefully controlled conditions can produce reliable temperature data even at the lowest temperatures required in this program, their use in the test loop for control of the refrigeration system would introduce many operational difficulties. For instance, the thermocouple would be mounted at the end of the inlet helium duct, and when the head assembly is removed for specimen changes, the thermocouple could accidentally get bent. It has been experimentally determined at Lockheed that a single bend of a No. 30 B & S gage thermocouple will introduce enough cold work into the metal to change the thermo-electric emf generated sufficiently to change the temperature indicated in the 30^{o}R range more than 1^{o}R. Another operation difficulty introduced by thermocouples is the necessity for maintaining the reference temperature bath.

Because of the factors discussed, the refrigerator is controlled by platinum resistance thermomemeters mounted in the inlet refrigerant gas manifold. One thermometer is mounted in the inlet manifold connection to each of the helium transfer lines. This sensor is located downstream from the heater for accurate measurement and control of the gas temperature to the individual test loops. Each of these sensors is connected to a temperature recorder-controller as originally designed when the sensors were to be in the test loop. A second set of platinum resistance thermometers is installed on the upstream side of the return manifold in the refrigerant return line from each test loop. The output from each of these sensors is recorded on one three channel printer-recorder. The specimen temperature is controlled by adjusting the inlet temperature controller based on the temperatures of both inlet and return gas streams.

2.5 CALIBRATION OF SPECIMEN TEMPERATURE WITH GAS STREAM TEMPERATURES

In the 30^{o}R temperature range, the temperature difference between inlet and outlet gas streams at the thermometer positions in the manifolds has been calculated to be about 8^{o}R. It is also expected that the gas temperature at the specimen will be very near the mean

of these two temperatures. For higher temperature ranges, the expected ΔT's between the inlet and return gas streams in the manifold are predicted to be higher.

Measurements of the temperature differences between the gas streams in the manifolds and that gas at the specimen will be made using an absolute thermocouple to measure gas temperature at the specimen and the platinum resistance thermometers in the manifolds. A differential thermocouple will be used to determine the temperature difference between the specimen and the surrounding gas because when temperatures are measured separately and subtracted, any error in measurement enters the calculation twice, thus making the error larger than it would be if the difference were measured directly. As previously mentioned, the leads from the thermocouple junctions in the test loop head assembly to the reference junction will be about 30 feet long and will traverse three major temperature gradients. It must also be noted that small lead wire is desirable to minimize heat transfer into the junction and that in the small gages copper thermocouple wire is more homogeneous than constantan wire. Therefore, the long leads for the differential thermocouple will be copper (probably No. 40 B & S gage) and the short (3 to 4 inches) section connecting the two junctions inside the test loop head assembly will be constantan (probably No. 30 B & S gage). The junction on the specimen will be mounted in a groove as previously described and the gas stream junction will be adjacent to the junction of the absolute thermocouple used to measure the gas stream temperature.

These calibration measurements will be made for each temperature at which tests are to be conducted at Plum Brook. They will also be made on each of the three types of alloys - aluminum, stainless steel, and titanium with the reactor operating at full power.

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3 EQUIPMENT FABRICATION

3.1 SHIELD FOR BEAM PORT HB-2

During this period, a suitable method of brazing the tungsten alloy to type 304L SST was achieved. A brazed butt joint using an 82% Au 18% Ni brazing alloy was accomplished in a furnace with an inert atmosphere.

Several tests were performed before approval was given to proceed with this particular brazing alloy. The alloy showed good flow and "wetting" characteristics, as well as good tensile properties. The ultimate strength of the brazed samples was in excess of 60, 000 psi.

Numerous other methods were tried during the period to obtain a solution to this problem. A Cu-Ni base brazing alloy appeared to meet the requirements, although the Au-Ni alloy gave more satisfactory results.

The tungsten alloy portion of the shield had been fabricated from ring sections, hot pressed and sintered together. Upon cooling, after the first brazing operation, it was observed that the joint between the first two ring sections closest to the braze joint was cracked. This crack extended about 120° around the periphery. It was concluded that this was the result of a defect in the original fabrication so another shield was made from a solid bar of tungsten alloy that had been hydrostatically compressed to obtain a uniform density. This unit was then rough machined and successfully brazed. Final welding of the 304L tubular sections to the remaining stainless tube, final machining, nickel plating, inspection and test will be performed during the next quarter.

3.2 TEST LOOPS

Loop Seal Leakage Tests - The seal grooves in the test loops were refinished to obtain a better surface finish. The bellows type seals

for which the grooves were designed were tried but leakage was still evident. Special modified metal "O" rings with an oval type cross-section are now being investigated as a means of solving the leakage problem. Upon receipt of these silver plated "O" rings, additional tests will be run.

Head Cover Modifications - The test loop heads were modified so that the cover can be welded onto the land at the aft end of the head. The forward end of the cover will terminate at the bolt flange. (See Figures 14 and 15.) The welding was accomplished by the electron beam method since all parts were final machined and no distortion could be tolerated. After welding, the weld bead was machined to proper size. The cover was terminated at this point so that the evacuation tube could be sealed again if it becomes necessary to reevacuate the heads. The end cover matches with the head cover at the bolt flange to maintain the 6" diameter configuration of the test loop.

Body Cover Evaluations - Single piece construction body covers were fabricated for the test loops using a rubber "O" ring at the aft joint. (See Figures 16 and 17.) Since the test loop heads were not available at the time, these covers were installed and checked for leakage using a blank plate at the forward end. No leakage was evident at the rear joint during these tests. Since the forward joint will be in the seal area before the pressure of the primary reactor water is applied, the fact that this joint is not leak tight will not effect the leakage rate of primary water into quadrant water.

Electrical Resistivity Instrumentation Installation - One test loop is being prepared for installation of instrumentation leads for electrical resistivity tests to be conducted by NASA. The same leads will be utilized at a later date when similar tests will be conducted by NASA on additional materials. Instrumentation will consist of 4 #16 copper wires, 2 #20 copper wires, and 2 pairs of 1/16" O.D. stainless steel sheath copper-constantan thermocouple wires.

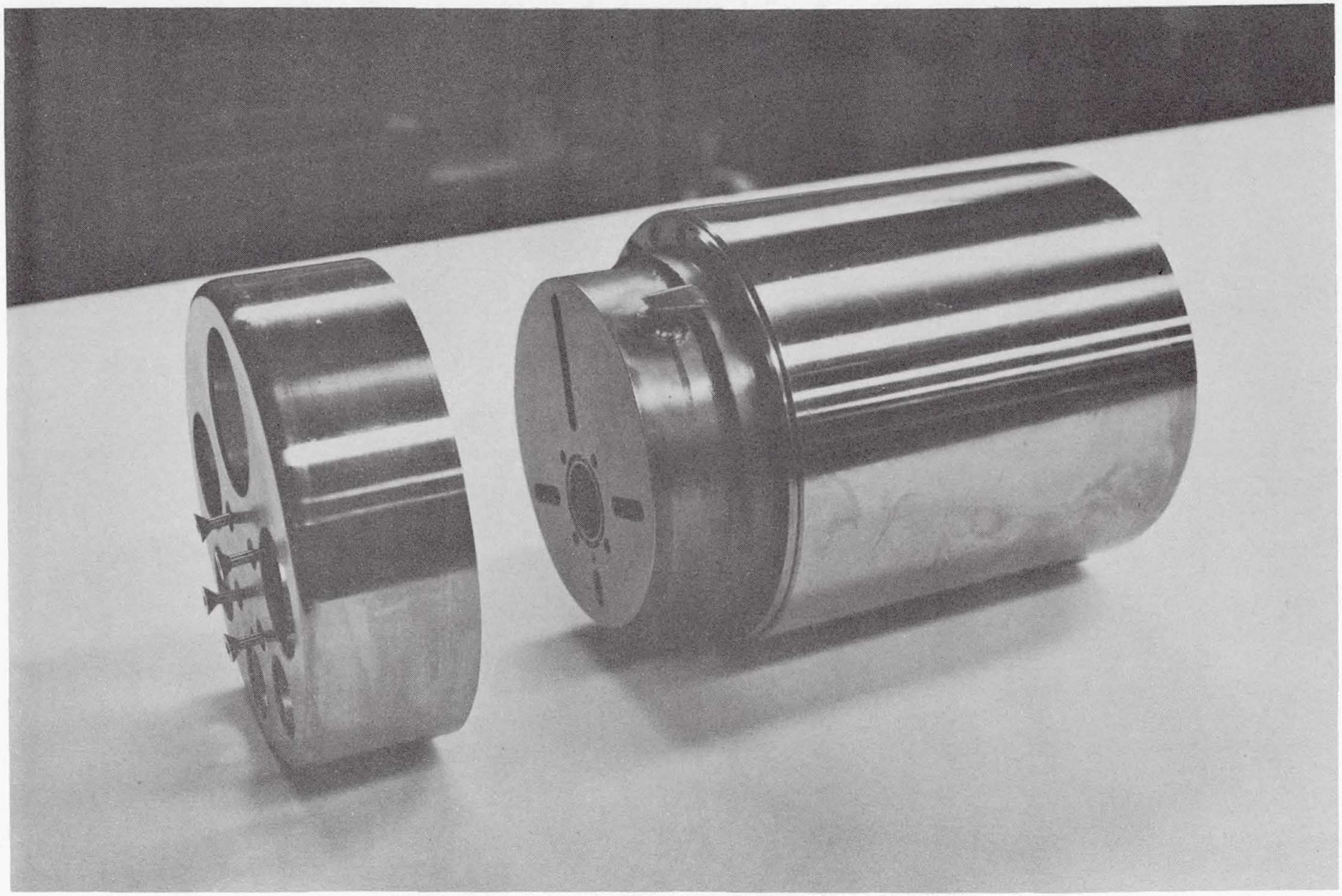

FIGURE 14 TEST LOOP HEAD & COVER

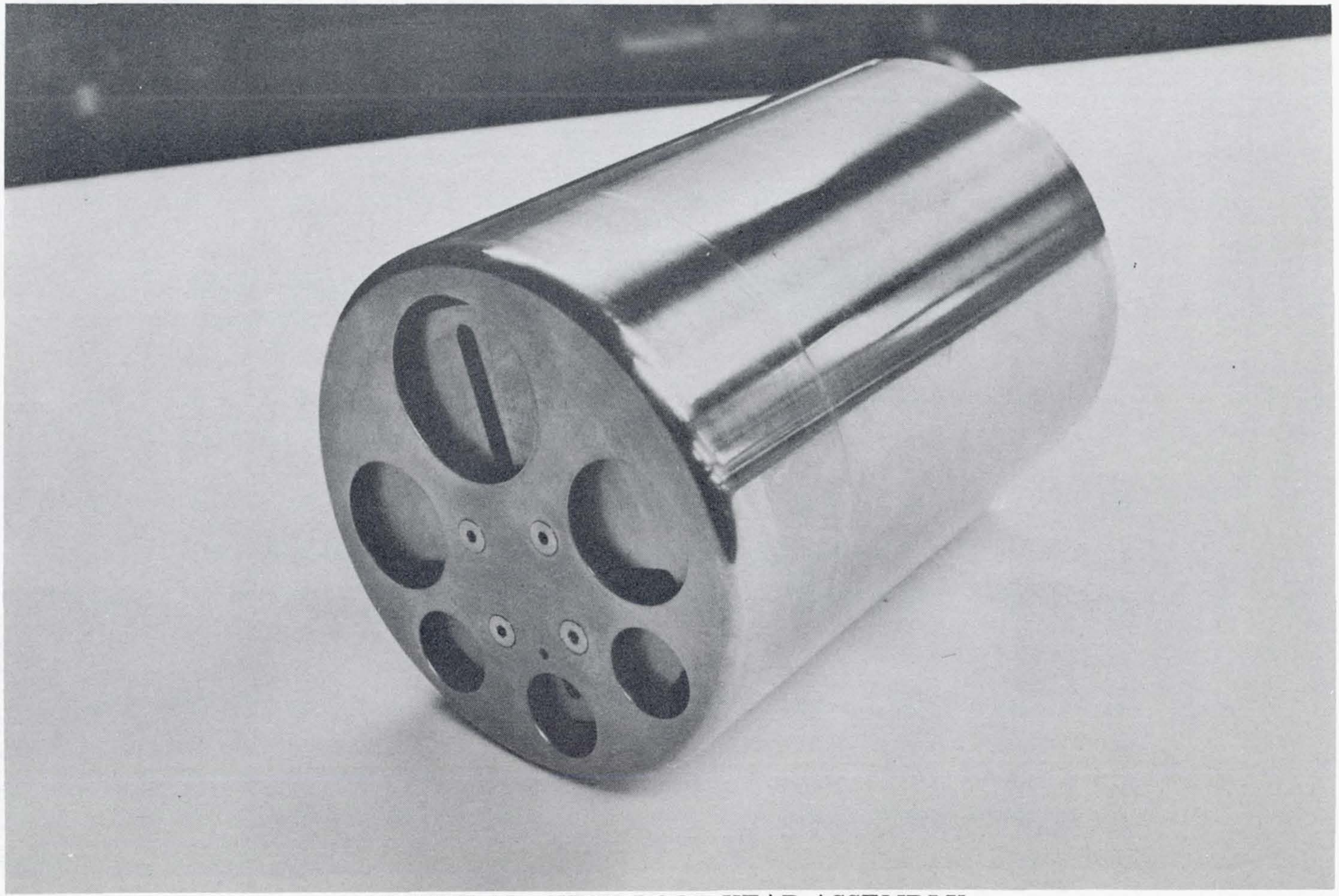

FIGURE 15 TEST LOOP HEAD ASSEMBLY

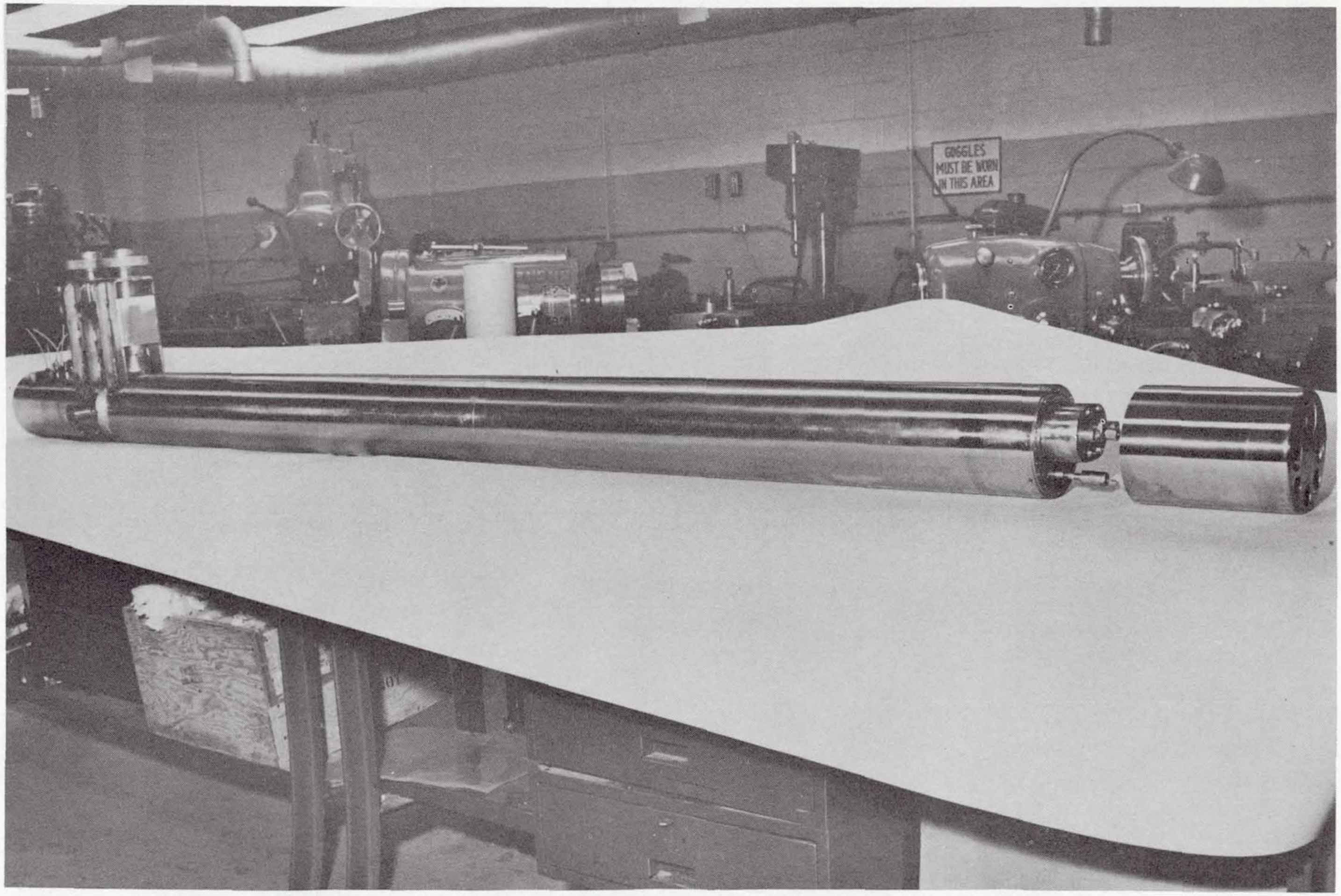

FIGURE 16 TEST LOOP, HEAD ASSEMBLY REMOVED

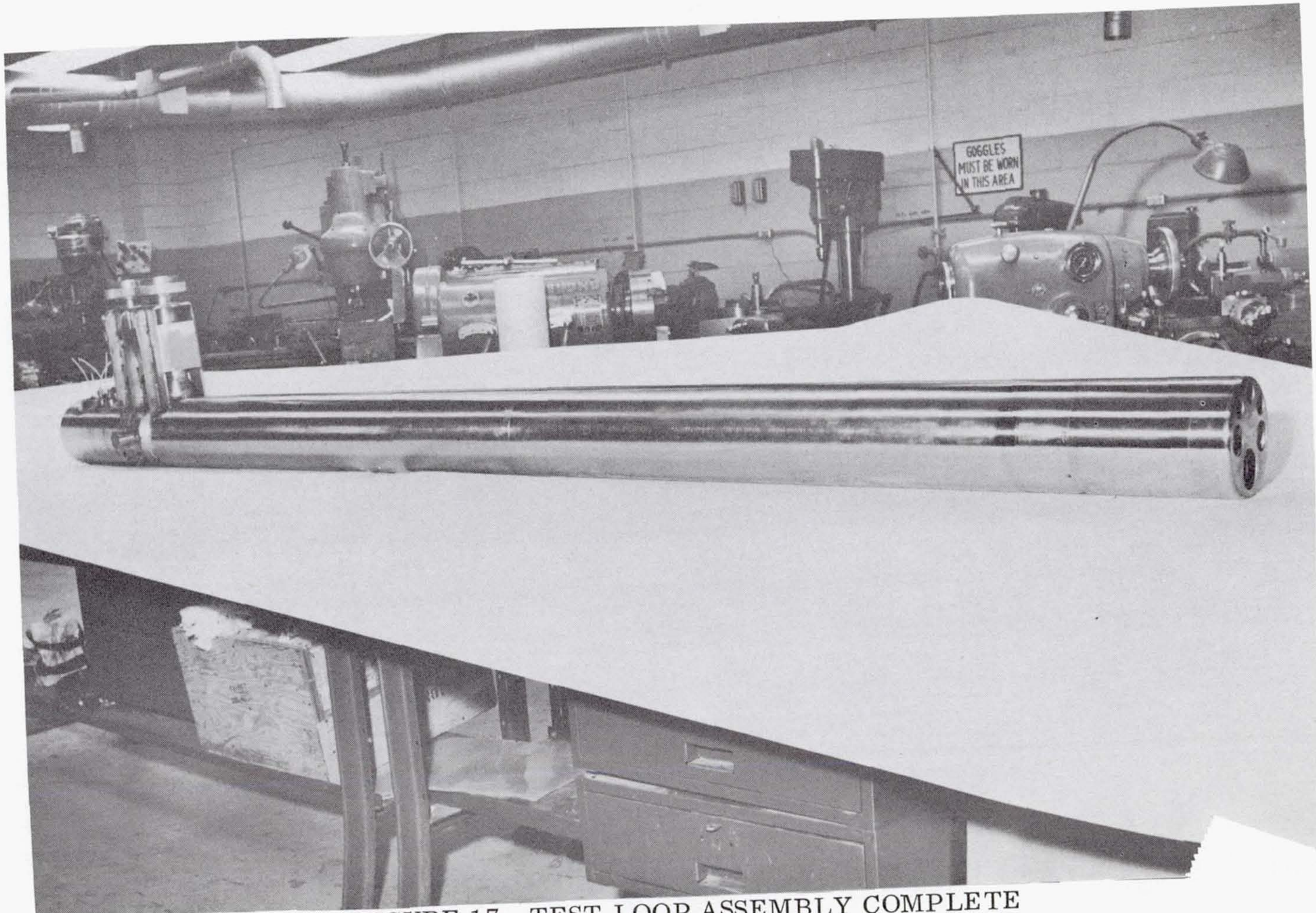

FIGURE 17 TEST LOOP ASSEMBLY COMPLETE

Hydraulic Cylinder Installation - Special stainless steel hydraulic cylinders for actuating the test loop pull rods were ordered and received. After receiving the cylinders, all were disassembled and thoroughly cleaned. The mounting flanges were modified for test loop installation and air bleed ports with special fittings were provided. The cylinders were then assembled, tested and installed in the test loops.

Test Data Console - A selector panel was designed, fabricated and installed in the test data console. The extensometer and dynamometer excitation voltages can be selected for any of the three test loops and their respective signals fed into the recorder.

3.3 REMOTE HANDLING EQUIPMENT

Most of the major handling equipment has been designed and is in the fabrication stage. A summary of the major equipment follows:

Item	Status
Air Lock Bridge	In fabrication.
Air Lock Cart	Fabrication complete, except awaiting completed design for method of securing to cask.
Test Loop Cask	In fabrication.
Cask Cradles (2)	In fabrication.
Cask Lift Rig Assy.	In fabrication.
Dummy Test Loop	In fabrication.
Test Loop Handling Tool in Quadrant	In fabrication.

Item	Status
Test Loop Handling Tool in Hot Cell Area	In design.
Transfer Lines Handling Tool	Design complete.
Test Loop Hot Cell Mobil Stand	In design.
Test Loop Body Cover Removal Tool	In design.
Cask and Cradle Slings	In design.
Cask to Cart Securing Device	In design.

3.4 HOT CAVE MOCKUP

The manipulators were completely dismantled, thoroughly cleaned and overhauled prior to installation in the hot cave mockup. The hot cave mockup was set up with the prototype test loop for the purpose of evaluating and constructing necessary remote tools for specimen loading and unloading. Several tools were built and evaluated and an electrically operated impact wrench was purchased. Training of personnel in the operation of the manipulation and ancillary equipment was initiated.

4 TEST PROGRAMS

Due to the concerted effort on fabrication and the "on site" installation of fabricated parts, no test data was obtained during this period. All testing personnel and operations were transferred to the Plum Brook Reactor Facility in preparation for in-pile testing. It is anticipated that much of the screening program data will be obtained during the next report period.

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5 EQUIPMENT INSTALLATION AT PLUM BROOK

This section is concerned with the status of the equipment installation at the Plum Brook Reactor Facility, with the exception of the beam port gamma shield which is discussed above.

5.1 SAMPLE CHANGE TRANSFER SYSTEM

The new hydraulic pump discussed in the previous Progress Report was received, installed and tested. It appears to meet all requirements of the system. The hydraulic motors were modified and passed a 10 hour endurance test with little change in performance characteristics. Spare hydraulic motors have been ordered and delivery is expected in October. These motors have a higher torque rating which provides a greater margin of safety and increases the ability to drive the test loops into the beam port against the 150 psi pressure of the reactor primary water.

The transfer system is installed and checked out as far as can be accomplished. The preliminary checkout of the hot cave beam port and the north table operation will be accomplished with the use of a test loop. Piping for the hot cave 6" slide type valve has been run as far as feasible until the hot cave is complete; likewise, the piping for the test loop cooling water was installed as far as possible until the beam port shield is installed. Upon installation of the shield, the transfer system tables and "stops" will be set and the entire system checked out.

Modifications were made to make the system compatible with existing facilities. This is in accord with the normal field type installation of equipment.

5.2 HOT CAVE

Fabrication of the special hot cave to be installed on the outside of Quadrant "D" wall in line with the HB-2 beam port began with the

blocks being pre-cast in Cleveland and transported to the Plum Brook Facility by truck. Some slight modifications were made to the blocks to conform to the variations in the structure of the quadrant wall and floor. Since the viewing window was oversize, it was necessary to remove 1/16" from the surface of the frame to allow installation. It was more feasible to remove material from the window frame than to send the window back to the vendor to be reworked to conform to the specifications. Completion of the hot cave is scheduled during the period covered by the next progress report.

5.3 REFRIGERATION SYSTEM

The installation and preliminary check out of the refrigeration system was completed during this quarter. In addition, the final performance tests were initiated and the majority of these were finished.

After all of the equipment associated with the system had been installed and checked out by the Arthur D. Little Company, tests leading to the final acceptance were performed for Lockheed. Included in this battery of initial steps was verification of all vacuum systems, ability of the system to hold static helium (leak tightness of all pressure components) and conformance of all equipment with the required specifications. After each item had been reviewed and the system found to be acceptable from the point of installation, the final performance tests were begun.

These final performance tests constitute the main progress during this quarter. A portion of the following summary of final performance tests are excerpts from the manual submitted by Arthur D. Little Company to Lockheed after the majority of test runs had been completed at Plum Brook.

The five temperatures at which the refrigerator was to be stabilized and tested for performance were $30^{o}R$, $150^{o}R$, $275^{o}R$, $400^{o}R$ and $540^{o}R$. These tests were to be conducted in a manner similar to that in which the preliminary tests were conducted at the plant of

the vendor. In each case, the test temperature represents the average of inlet and return line temperatures of the simulated in-pile loop.

30°R Final Performance Test Run at Plum Brook

It should be borne in mind in reading this report that the temperatures established on the various test loops were arbitrary and that the control settings were adjusted to conform to the requirements of the system at these temperatures. The control system is quite flexible and can, therefore, be adjusted to meet the various operating requirements in response to different temperature settings from those given.

The method of determining transfer line heat leak at the 30°R level was as follows:

The system was operated at rated speed with all three sets of transfer lines and calorimeters open. The throughflow valves in the valve chest of the line, the heat leak of which was to be evaluated, were closed to shut off the calorimeter. The result of this was to reduce the heat flux into the system by the amount of the calorimeter heat leak. In order to prevent the return manifold temperature from dropping below the set valve, it was necessary to add that amount of heat to the main heater that represented the calorimeter heat leak. Having done this and marked the increase in watts, the valve chest through-flow valves were next opened and watts removed from the main heater until equilibrium was established at the set return manifold temperature. Thus, two readings on calorimeter heat leak were obtained, one when the calorimeter was closed off and another when the calorimeter was reopened.

The combined heat leak of the transfer line and calorimeter was then determined by closing off the inlet valve to the entire loop, again adding heat to the main heater sufficient to hold the return manifold temperature at set point. The increase in watts measured the transfer line and calorimeter heat loss.

The foregoing procedure was carried out for the three (3) sets of transfer lines and it was conclusively demonstrated that the transfer lines were below the specified value of 100 watts maximum heat leak.

The next evaluation performed was that of determining the total capacity of the system at the test temperature, 30°R. In order to establish a capacity for the tolerable range of values, two methods were used. In the first, the total heat load on the system was tabulated and the remaining specified load was placed upon the main heater. After equilization, the manifold temperature read 29.8°R - below the specified requirement of 30°R. Heat was then added with the main heater until a return manifold temperature of 31°R was obtained. The maximum value for capacity as attained in the second case was 1280 watts. This value is believed to be on the conservative side and yet it demonstrates that the refrigeration system has ample capacity.

The next operation was the simulation of a loop in-pile, one loop in the hot cave - by pass condition - and the third ready for cool down prior to entry into the reactor. Using the same operating conditions as those of the total capacity test, the test loop was cooled down by means of the automatic temperature controller. During the test, the following observations were made:

The temperature at the inlet to loop 2 (in-pile), controlled by the heater for that loop, remained constant within less than 1/2°R; the temperature at the outlet sensor in loop 2 remained constant within less than 1/2°R; the temperature of the return manifold sensor returned to its original value in less than 30 minutes; the return temperature of the cool down loop was back to its initial value 18 minutes after the start of the test; and all system temperatures were fully stabilized in less than 30 minutes and the temperature of the in-pile loop remained within ±1°R of its prescribed value.

After completion of the above, simulated removal of the in-pile cryostat followed by insertion of the cooled down cryostat was accomplished. This operation was shown to be possible within the required time limit and the test temperature of the sample was maintained.

All of the requirements for satisfactory operation of the refrigeration system at 30°R were fulfilled and tests of a similar nature were run at the pre-set temperatures of 150°R, 275°R and 400°R. Capacity and system control were demonstrated to be within the requirements as specified.

The 540^oR point was not conducted at this time because of an accumulation of moisture in the system. At the 540^oR point this moisture, previously frozen at lower test temperatures, accumulated in the expansion engines making it impossible to continue the test.

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6 NUCLEAR INSTRUMENTATION (DETECTORS)

The purpose of the nuclear instrumentation portion of the NASA-Lockheed program for materials testing at cryogenic temperatures was to continuously monitor the fast neutron flux and the gamma-ray dose rate at a position very near the test specimen irradiation position. Preliminary feasibility studies showed that these two functions could best be performed with a fission chamber and an aluminum rod type calorimeter, respectively, with the expected fluxes and dose rates at the test specimen location.

6.1 FISSION CHAMBER

Design considerations of the fission chamber were fast neutron sensitivity, gamma insensitivity, radiation resistivity (both from a dynamic and a static standpoint) and reliability. After preliminary experiments were run, it was decided that the most feasible design would be a parallel plate type chamber with a plate area of approximately 1 cm^2. The plate spacing is 0.140". Further experimentation showed that the optimum gas pressure is 60 psia; i.e., the best operational characteristics are obtained with this filling. The fill gas is pure argon - thus chosen because of its nuclear and chemical characteristics. Compound fill gases or gas mixtures tend to contaminate the chamber with extended radiation exposure.

One of the most difficult design problems associated with the fission chamber was the transmission of the chamber signal (pulses) to the preamplifier. Because of limited space and because of the intense radiation fields in the vicinity of the chamber itself, it was essential that the pulse preamplifier be 8' removed from the fission chamber; hence, great pulse amplitude losses are encountered. The low noise preamplifier in use is quite satisfactory for fission pulses; however, alpha pulses cannot be seen over the long chamber-to-preamp cable. Alpha pulses can be seen by connecting the chamber directly to the preamplifier. There is one fission plate per chamber and the fission plates contain approximately 2×10^{-8} grams of N_p^{237} each in the form of neptunian oxide. The

chamber was designed to give a reasonable count rate in a fast neutron flux of 2×10^{-12} n/cm^2/sec. The chamber is electroplated with 0.005" of calcium to reduce the thermal neutron response. With expected thermal neutron fluxes and gamma dose rates, contributions from thermal neutron fission and gamma fission will be negligible.

The fission chamber-to-preamp cable consists of a small copper wire conductor with ceramic insulators extending 12" from the chamber and with polyethylene insulation from that point to the preamp. This conductor with its insulation is in a 5/16" I. D. stainless steel tube; thus making up a coaxial cable.

Thorough performance tests were made on ten chambers at the University of Virginia Swimming Pool Reactor. The chambers were inserted into a partially water filled tube adjacent to the reactor face in a fast neutron flux of approximately 1.7×10^{10} n/cm^2-sec. and a gamma dose rate of 4×10^5 r/hr. Gamma pile-up and fission pulses were observed from each chamber. In addition, several other experiments were performed with particular chambers in order to determine the operating characteristics of a typical chamber. The specific objects of these experiments were (1) to determine the degree of linearity of the chamber in counting fast neutrons, (2) to see if the pulse height versus count rate curve were sufficiently flat in high gamma dose rates to allow satisfactory operation, (3) to see if fast neutrons could be counted satisfactorily in the presence of intense gamma dose rates with negligible interference from gamma pile-up pulses, and (4) to see if the chamber voltage versus count rate curve were sufficiently flat to allow satisfactory operation with reasonable voltage regulation. Results showed that the chambers are quite adequate for their intended design. Thirty-five percent (35%) of all fission pulses can be counted in the presence of a 4×10^7 r/hr gamma field without interference from gamma pile-up pulses. It will be necessary for each chamber to be calibrated with foils prior to data evaluation.

Considerable care is required in the installation of chambers in the cryostats. The coaxial cable is filled with an inert dry gas and kept cool during all welding and soldering operations.

6.2 CALORIMETER

Because of the magnitude of the gamma ray dose rate at the desired point of measurement, a calorimeter was selected as being a good detector. After further consideration, it was decided that an aluminum rod type calorimeter with the proper sensitivity would be used. Aluminum was closen because (1) of its thermal conductivity constant and (2) of the similarity of its mass absorption coefficient curve to that of air.

The principle of the rod type calorimeter is that the energy deposited in the rod must be conducted down the rod to a heat sink. The temperature gradient along the rod and the conductivity of the rod may be used to determine the conductive heat loss. In the steady state condition, the energy loss is equal to the energy absorbed by the rod from the radiation field.

The temperature gradient along the rod is measured by two thermocouples a known distance apart along the rod. For this particular calorimeter the sensitivity is:

$$r/hr^{-1} = 1.0322 \times 10^{7} \, (T_1 - T_2)$$

Two copper-constantan thermocouples are in each calorimeter and are connected to a Honeywell Model SY153X22 two pen recorder. This recorder has two complete and independent emf measuring circuits and indicating pens. One channel is used to obtain the base temperature of the calorimeter by measuring the emf produced by the copper-constantan thermocouple located at the base or heat sink. The other recorder channel is used to measure the temperature difference between the two thermocouples. The temperature difference is obtained by measuring and indicating the emf produced between the two constantan wires, one from each thermocouple. This emf is due to the two opposing constantan-aluminum junctions formed by the two thermocouples.

Ten calorimeters have been constructed and are ready for installation into the test loops. Since this type of calorimeter is an absolute energy absorption measuring device, it will not be calibrated against other gamma dose rate indicating devices.

6.3 NASA INSTRUMENT MODEL 1201

This instrument combines a fission chamber H.V. supply, linear amplifier, scaler and count rate meter on a single chassis for standard rack mounting.

The instrument was completed and checked out and has been used to verify operation of a number of the small fission chambers.

A minor modification has been made on the instrument recently - the BNC connectors for high voltage and signal input were moved from the rear chassis skirt to the front panel. This will allow access to these points to interchange fission chambers.

APPENDIX A

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